Factors influencing the performance of near surface ground energy collection and storage systems

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Presentation overview

- Introduction
- Modelling Framework
- Case study: Inter-seasonal heat storage
    - Impact of surface conditions
    - 2D vs 3D
    - Snow / ice cover
- Overall conclusions

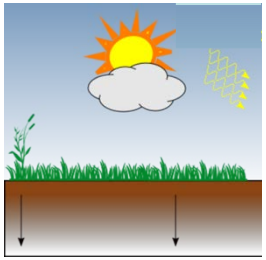
Near surface ground energy collection and storage systems

- Energy source / storage / management
  - Ground source heat
  - Shallow energy piles
  - Geothermal energy
  - Passive heating and cooling of buildings

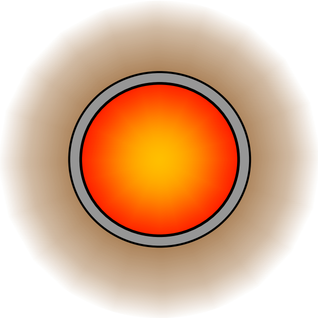
- Infrastructure protection
  - Pavements (e.g. roads, runways)

Factors influencing performance

- Performance highly dependent on:
  - quantity and temporal variation of energy in near-surface soil layer
  - design of the installed system
- Key processes include

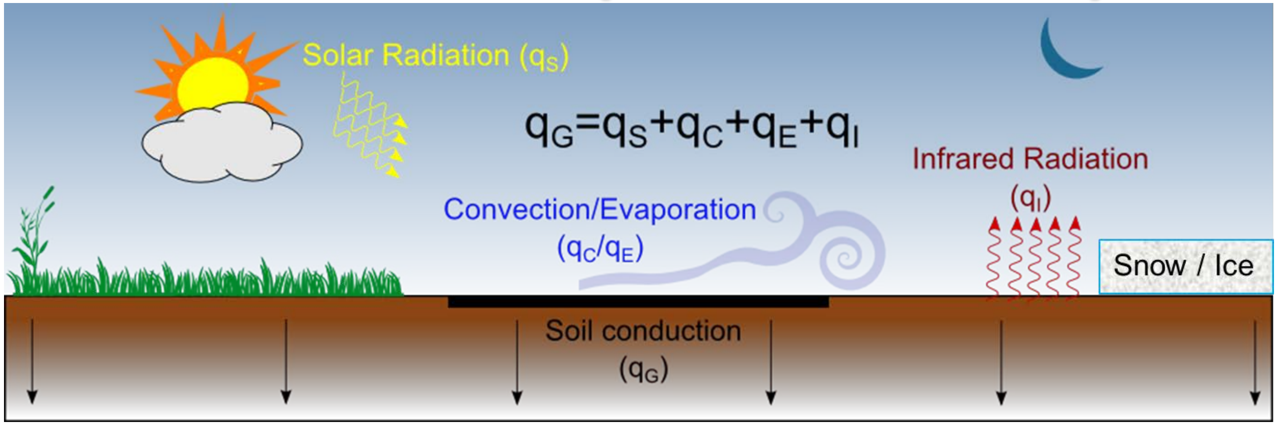


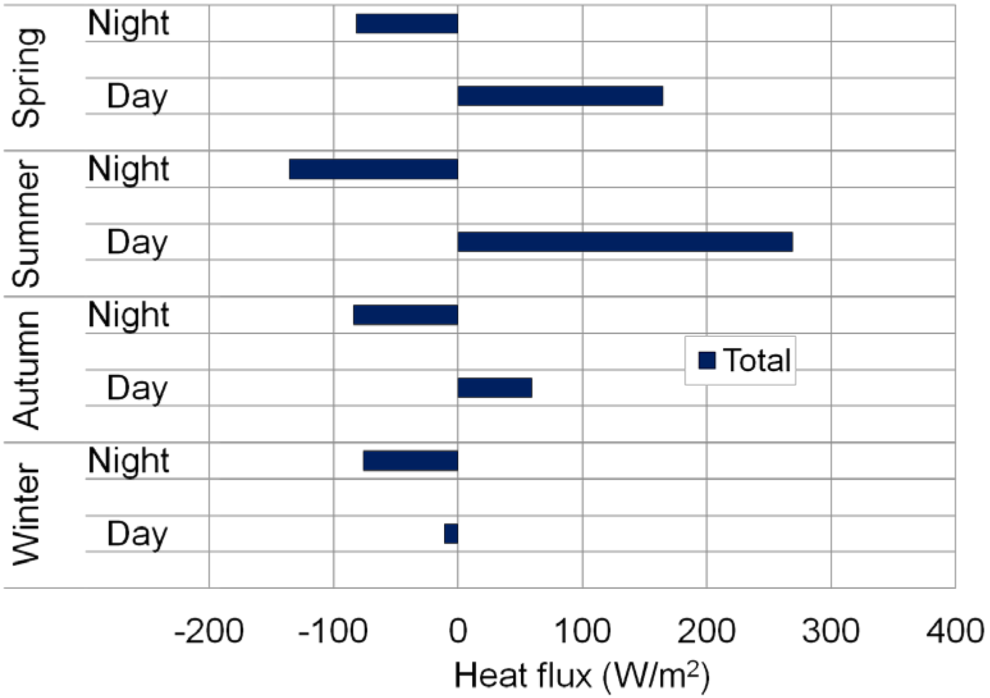
  - Transfer of heat between the ground surface and the atmosphere (surface fluxes);
  - Movement of heat within the engineered soil mass



  - Transfer of heat through soil : pipe interface
  - Movement of heat energy within the collector and storage systems

Typical surface fluxes (UK location)





Theoretical formulation - Surface fluxes

- Surface fluxes

solar radiation

evaporative

$$-k\frac{dT}{dx} = (1-\alpha_S)R + \sigma\varepsilon_G\left(\varepsilon_s T_{a,k}^4 - T_k^4\right) + h_E(q_a - q_G) + h_C\left(T_a - T\right)$$

infrared radiation

convective

  – Definition of heat transfer coefficients h_E and h_C:
    - Turbulent approach – Jansson (2006)
    - Non-turbulent – Edinger & Brady (1974) / Herb et al, 2008

- Vegetated soil
  – Canopy cover – Best (1998) and Deardoff (1978)
    - Separate heat balance equation for the canopy surface

Theoretical formulation - Surface fluxes

- Diurnal Shading

  - Diurnal shading factor, D_s to modify the solar radiation term

$$R_d = RD_s$$

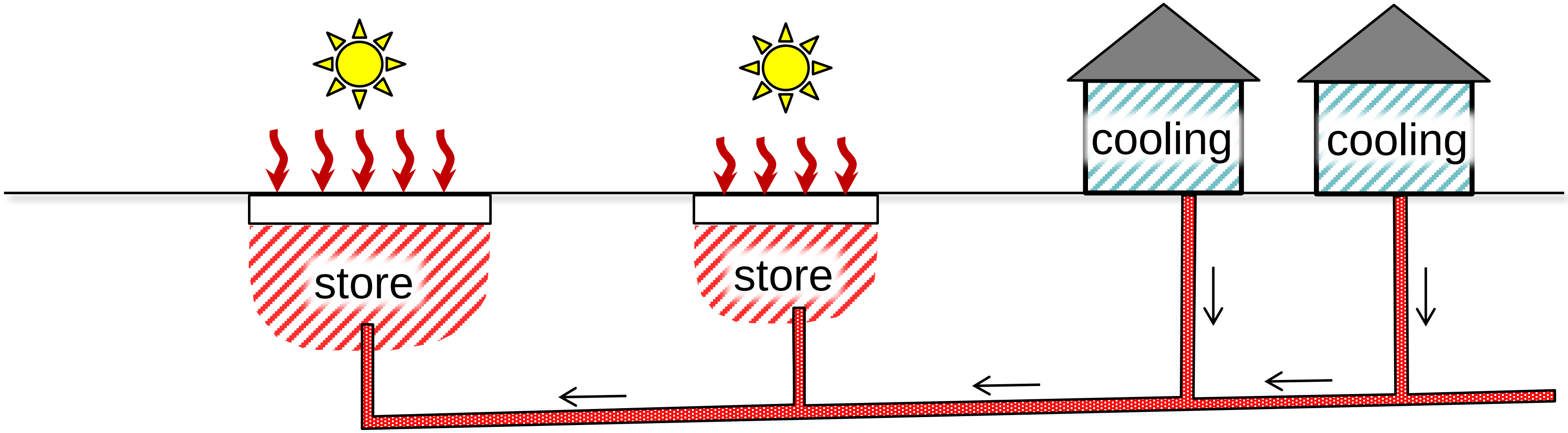
solar radiation

$$-k\frac{dT}{dx} = (1-\alpha_S)R_d + \sigma\varepsilon_G\left(\varepsilon_s T_{a,k}^4 - T_k^4\right) + h_E(q_a - q_G) + h_C\left(T_a - T\right)$$

Case Study: Inter-seasonal Heat Storage in Soils

- Utilises variations in seasonal conditions to allow storage / use of heat.
- Management of various infrastructure assets:
  - Roads
  - Airport stands / buildings
- Main source of heat from surface fluxes and buildings

Scenario 1: Summer
Collection and heat dumping



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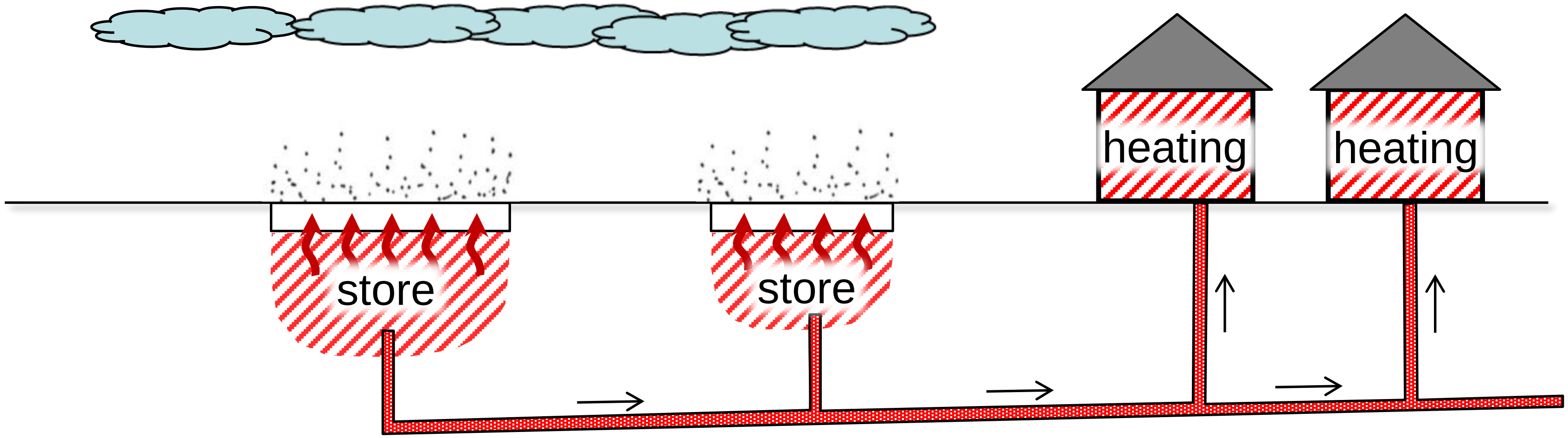
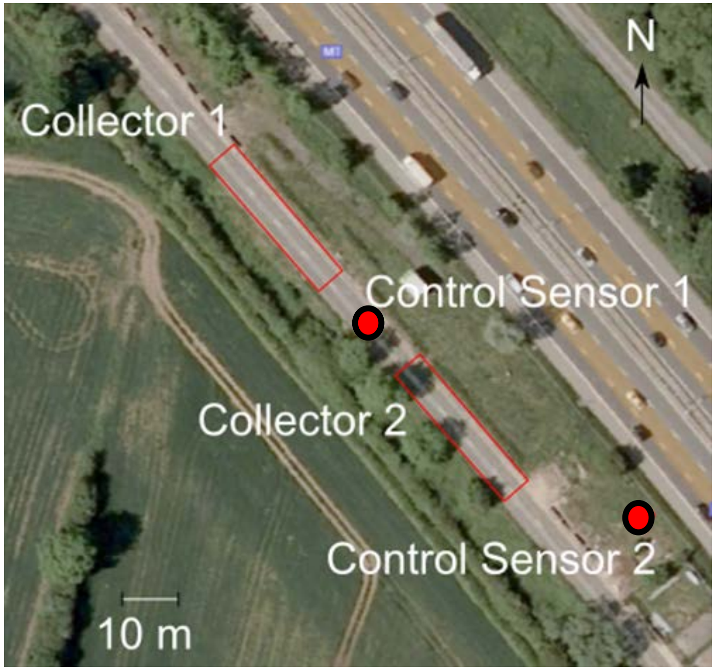
Scenario 2: Winter

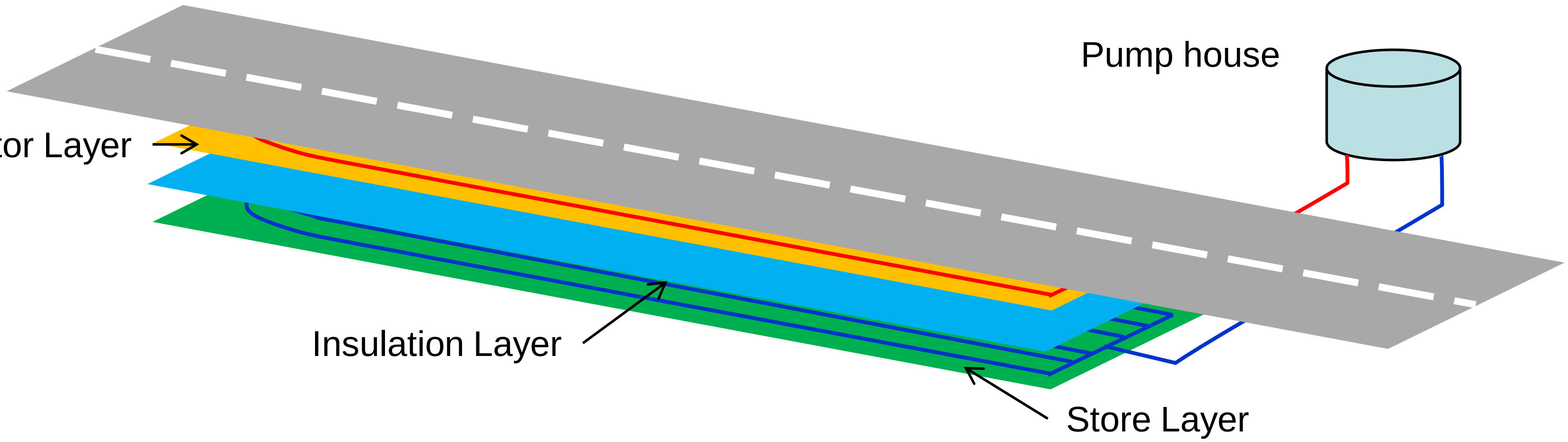
Surface snow / ice management and building heating



Case Study

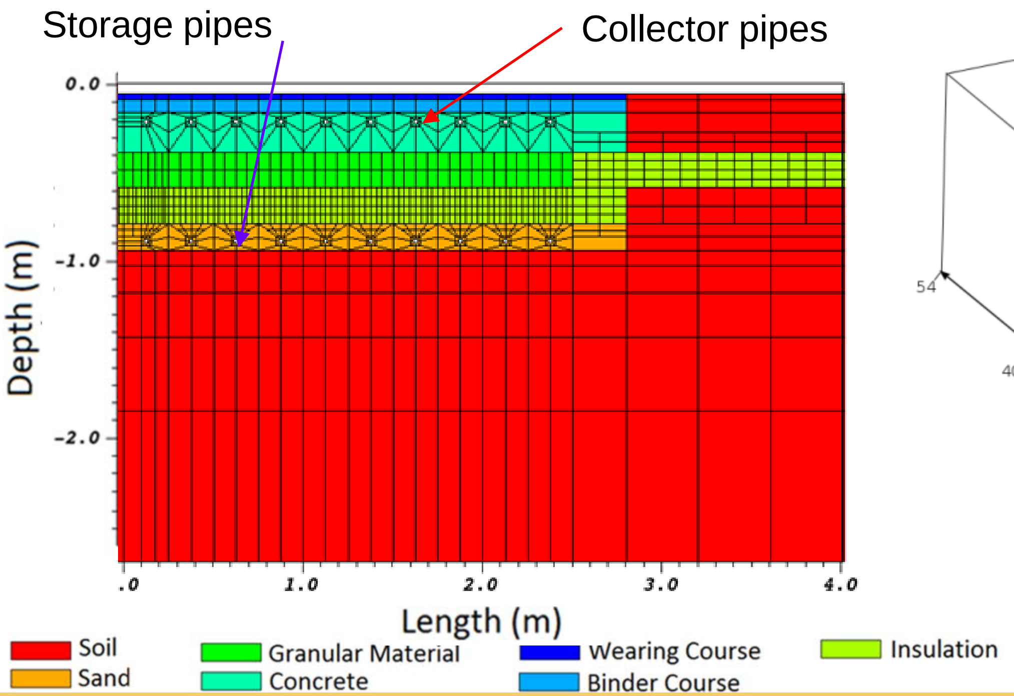
- Inter-seasonal heat storage demonstration project performed by the Transport Research Laboratory (Carder et al, 2007)
- Two year-long experiment
- Closed loop system

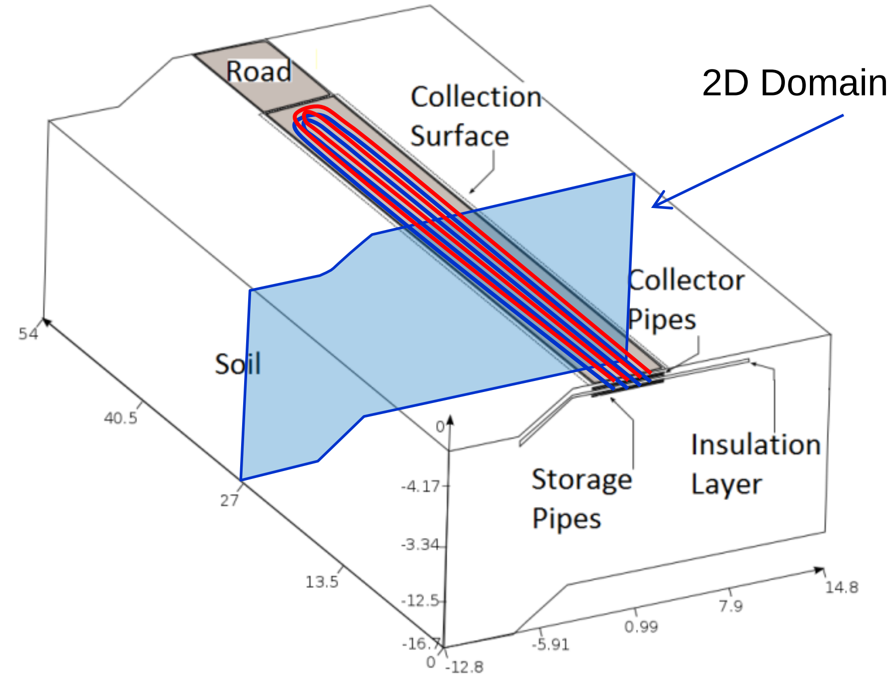




Modelling of heat collection and storage

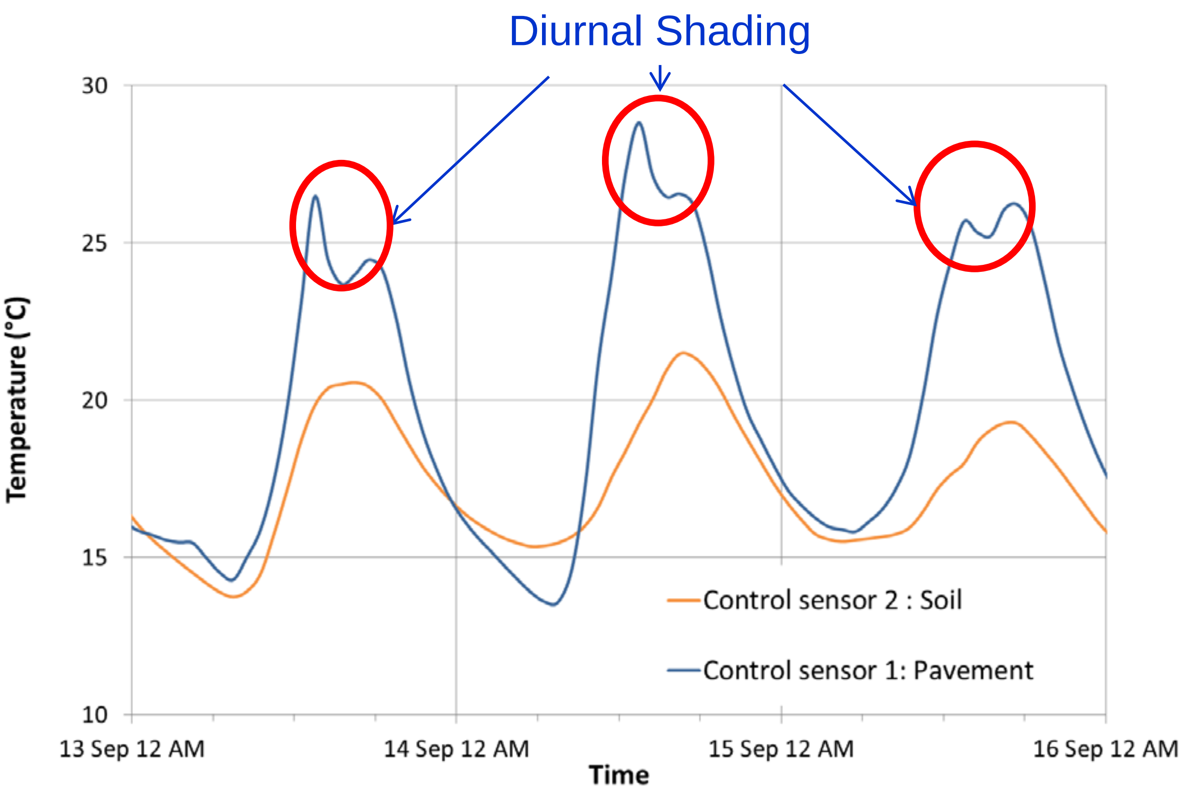
- Model of the ground and the heat collector / store arrays
  - Standard heat transfer or coupled TH or THM balance eq(s).
  - Surface fluxes, Diurnal shading , Soil-Pipe interface
- 2D or 3D Soil mass + 1D heat transfer within storage and collector pipes
- Validation against field scale tests.

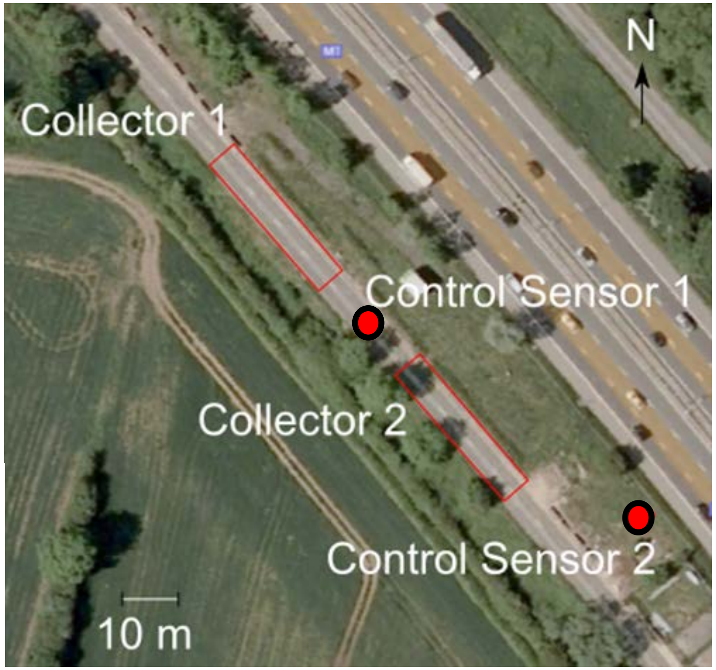




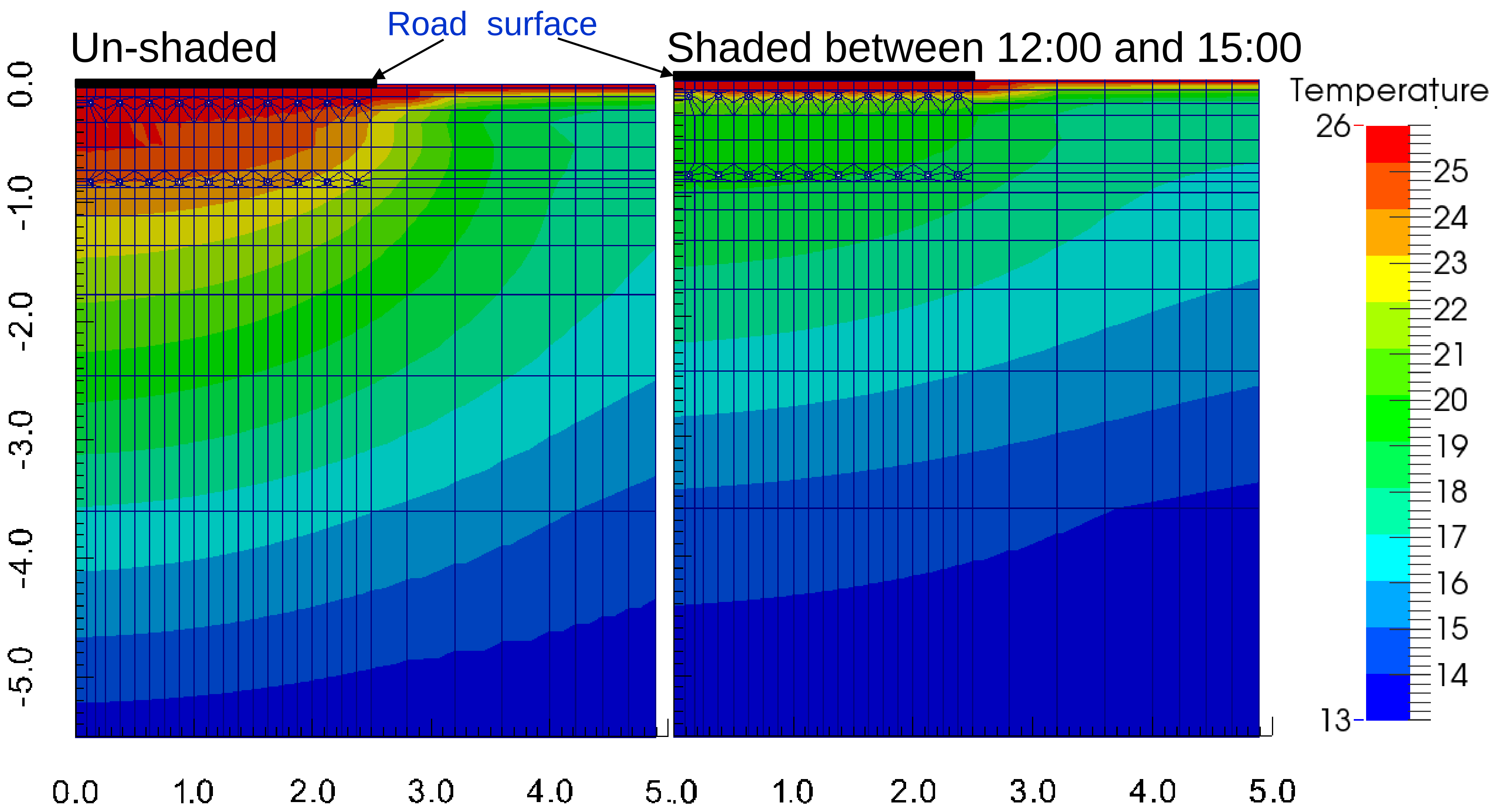
Impact of surface conditions

- Sensor 1 – Pavement (0.01m depth)
  – Variable shading
- Sensor 2 – Soil
  – Vegetation present

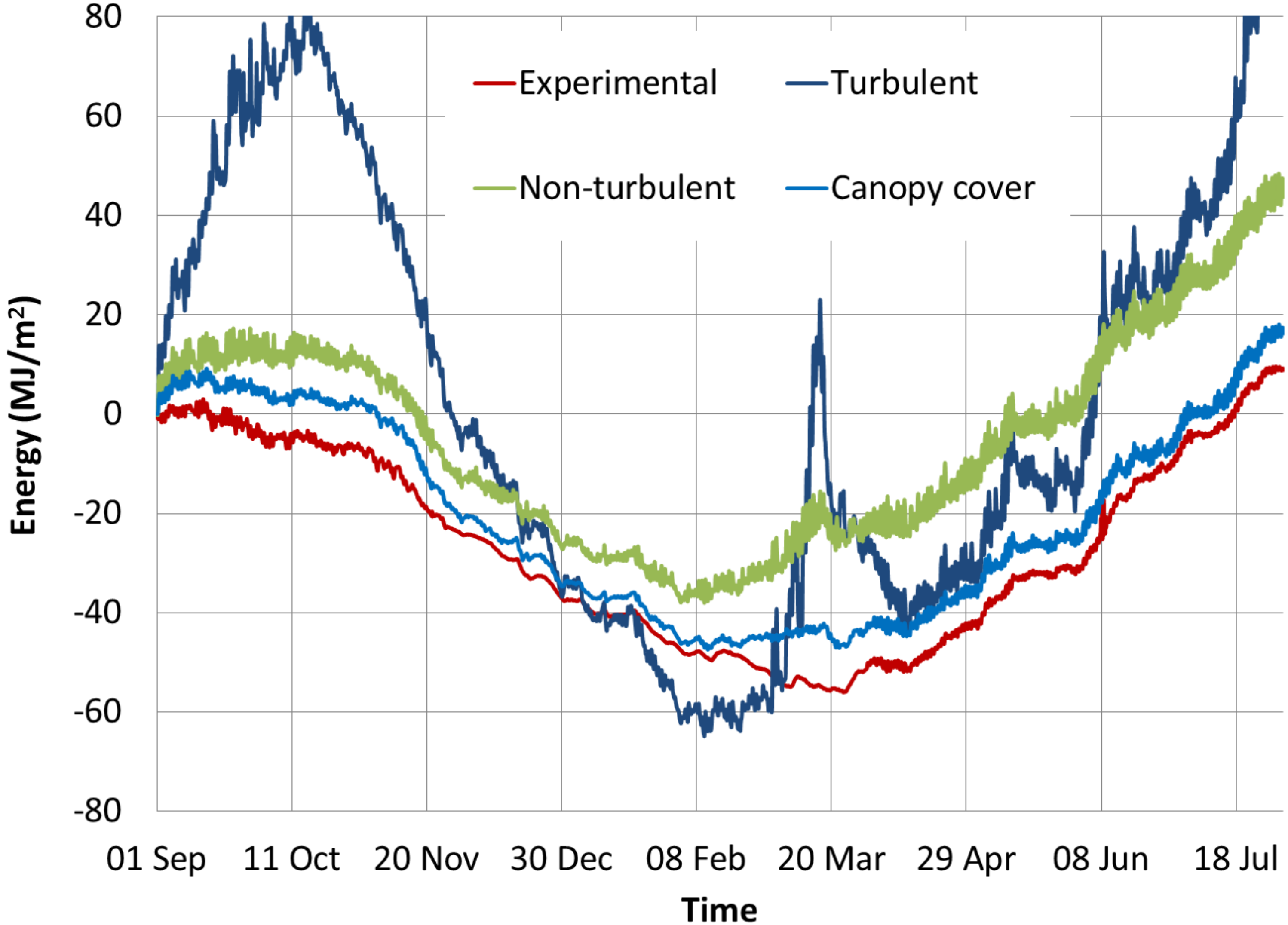




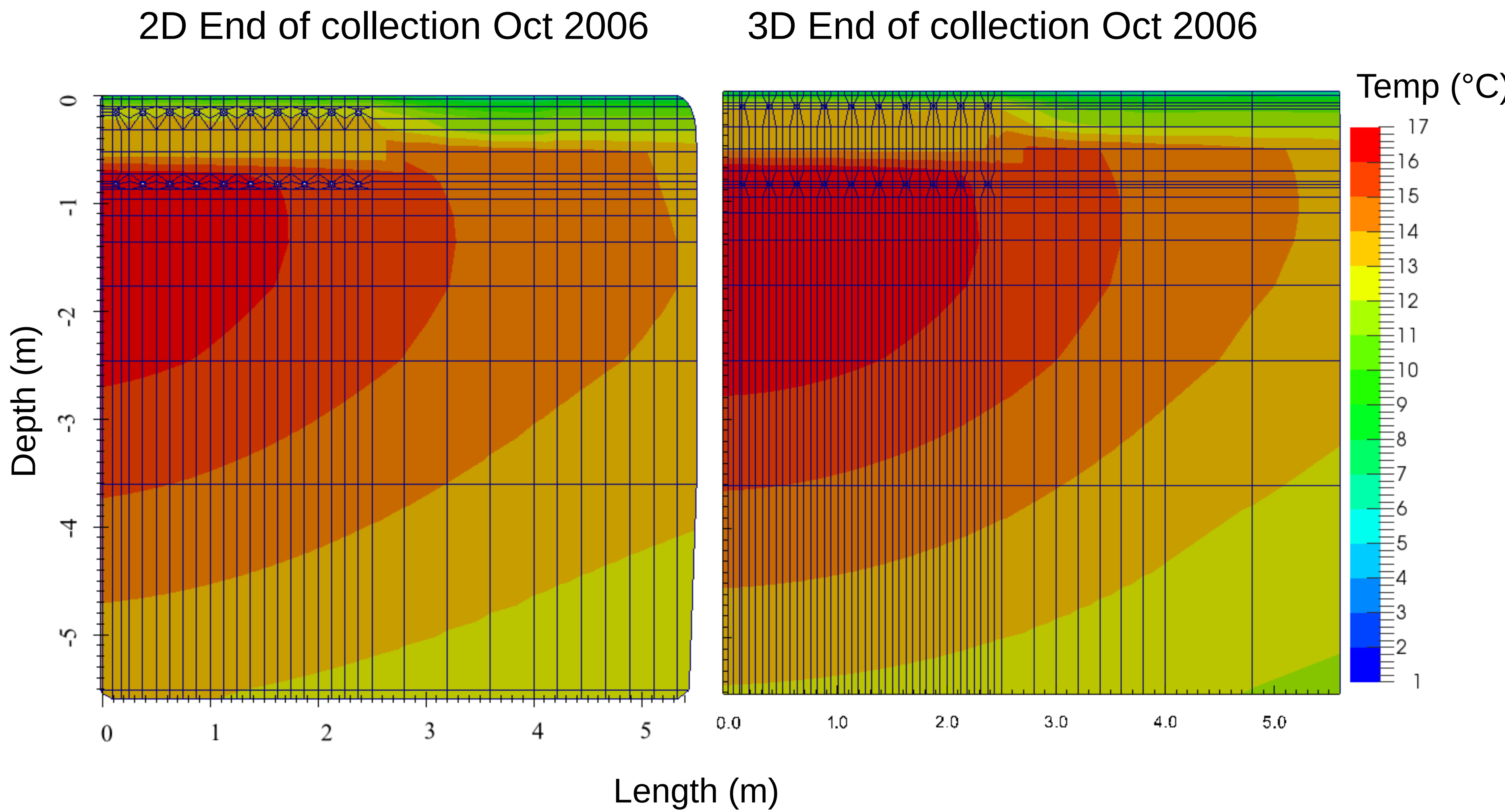
Impact of Diurnal Shading (2D Model)



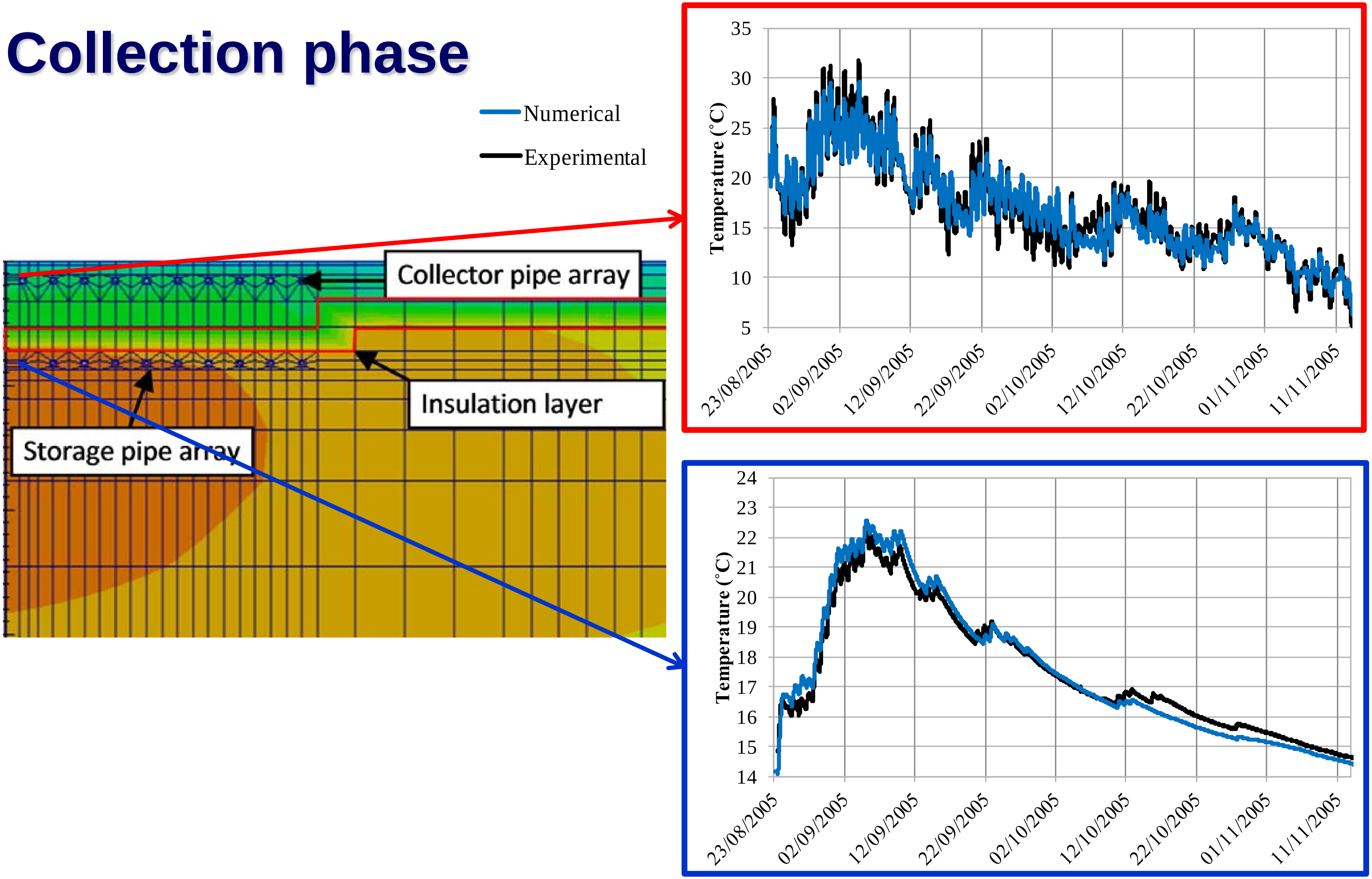
Sensor 2 – Stored Thermal Energy 1D soil column



Results: Temperature field 2D v 3D



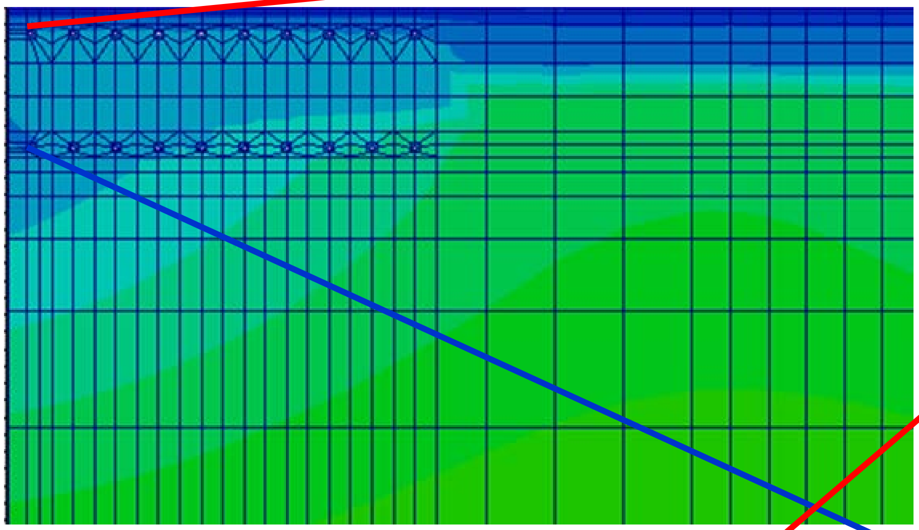
Collection phase

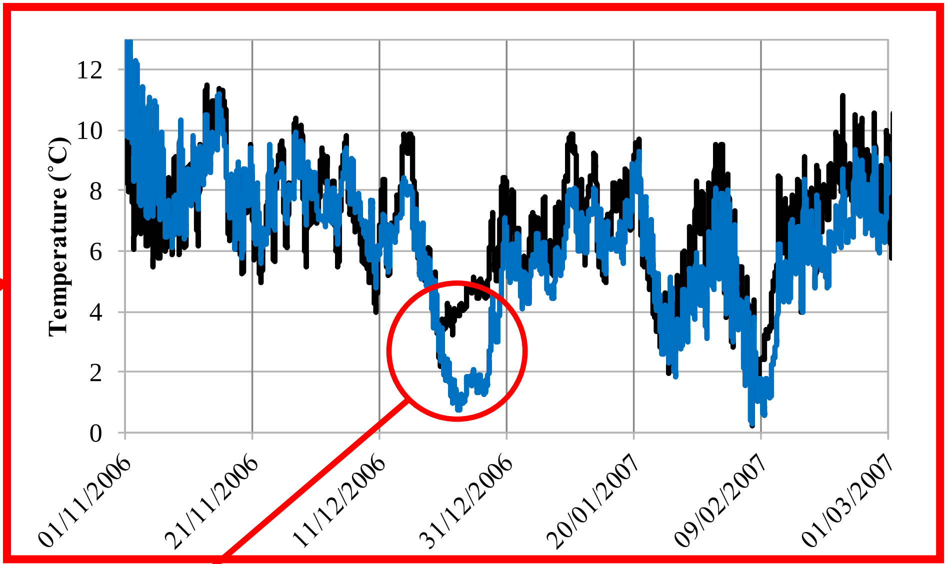


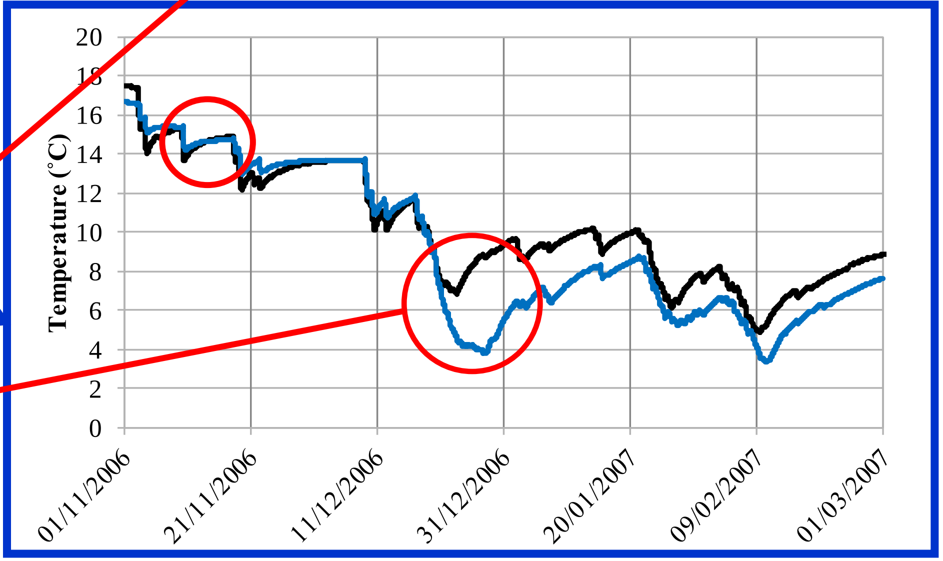
Usage phase

Numerical

Experimental







Snow fall

Conclusions

- Correct assessment of the nature of the heat transfer process occurring on the surface of the soil is of critical importance for the estimation of the amount of energy stored in the ground.
- Of particular importance is the correct representation of low level vegetative canopy cover, diurnal shading and snow/ice cover.
- Thermal properties of the soil mass in the store impact on the ability of the system to store and supply energy efficiently.
- Need to balance additional model complexity with uncertainty related to surface features when moving from 2D to 3D.
- Innovative materials where properties can be controlled could improve efficiency and are currently being investigated.